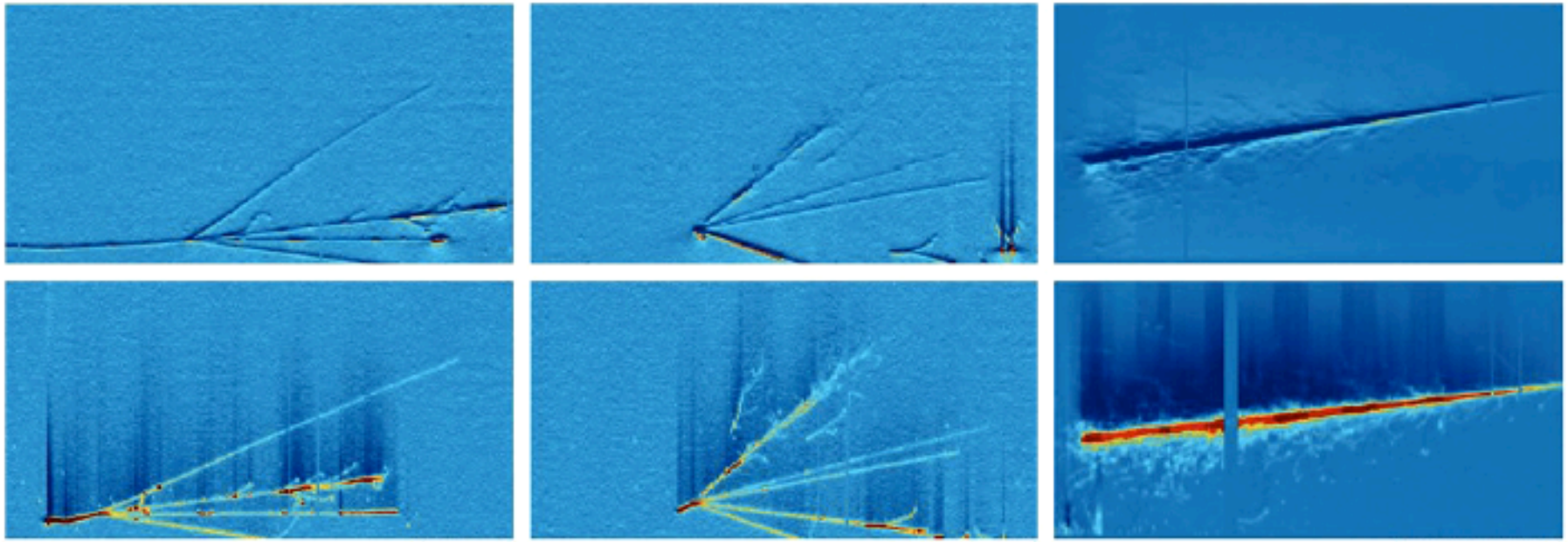


The ArgoNeuT LArTPC:

a dedicated Experiment for neutrino Cross Section measurement at FNAL

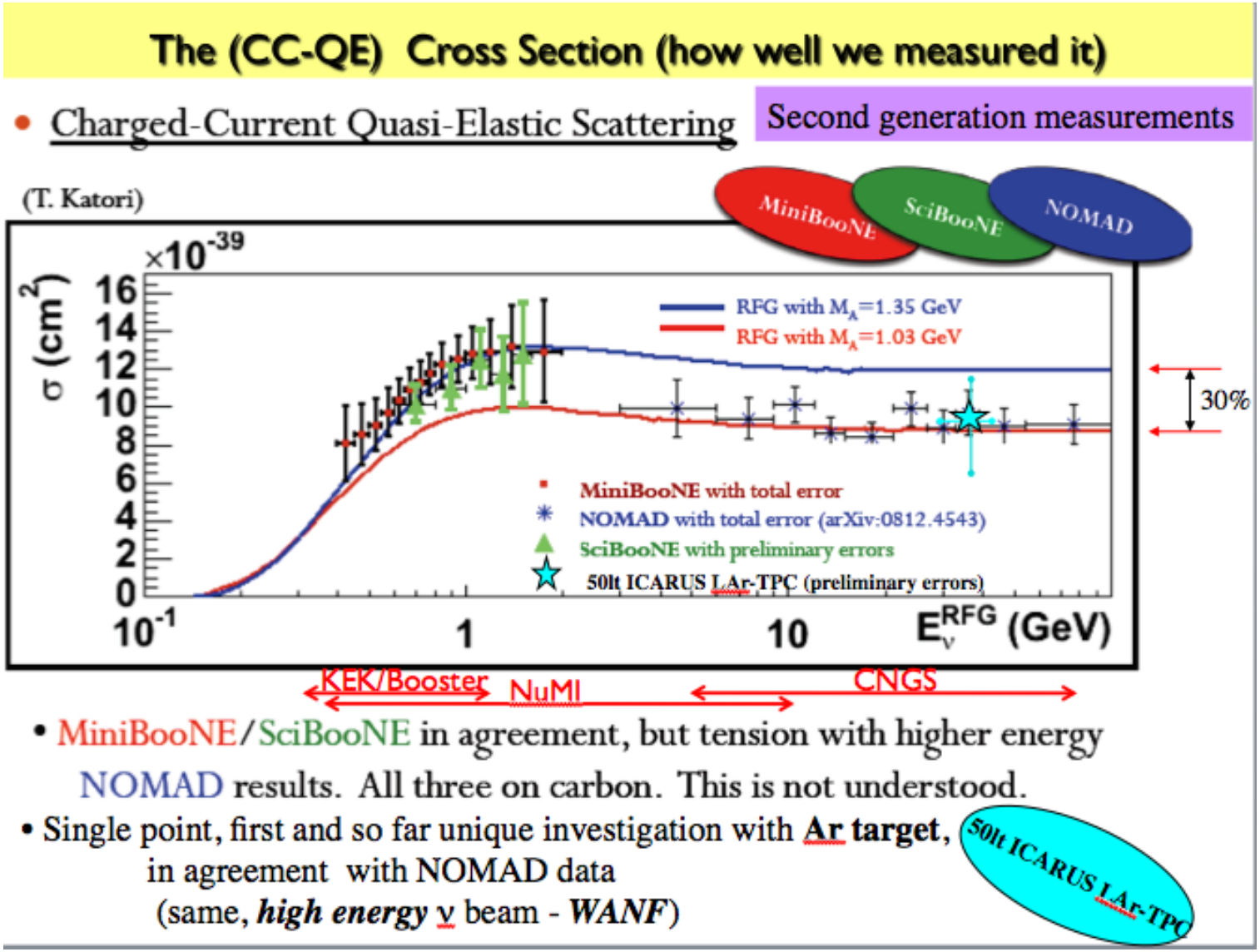
NOW 2010

September 7th, 2010

Ornella Palamara
Laboratori Nazionali del Gran Sasso

✓In the recent years, due to the increasing interest on LAr-TPC technology in the US, a dedicated experiment (ArgoNeuT, 2007) has been included as a first step in a graded program towards massive LBL neutrino oscillation experiments.

✓One of the main uncertainties in the next generation long baseline oscillation experiments is given by the neutrino-nucleus interaction cross section in the "few-GeV region".



ArgoNeuT Physics Goals

- Measure charged-current cross-section in the "few GeV" (1-5 GeV) range:
  - CC Quasi-Elastic (QE) channel
  - CC Resonant (RES: $\Delta \rightarrow \pi$ N) channel

  with unprecedented sensitivity to products of FSI (vertex activity characterization)

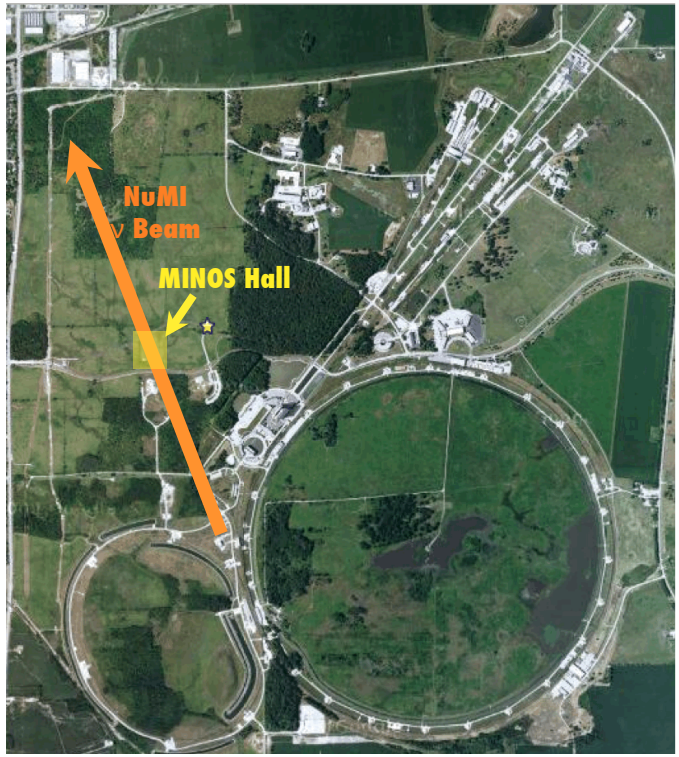
- e/γ separation study and optimization ⇒ superior background rejection
  - Important for ν_e appearance: excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
  - Particle identification from energy deposition (dE/dx) measured along track

- Develop reconstruction techniques useful for all future LArTPCs:
  - full 3D reconstruction of the event topology
  - precise calorimetric reconstruction of deposited energy and Particle Identification

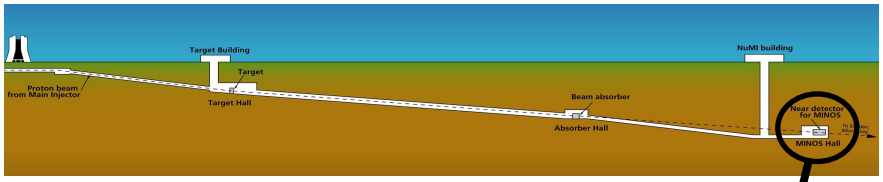
ArgoNeuT

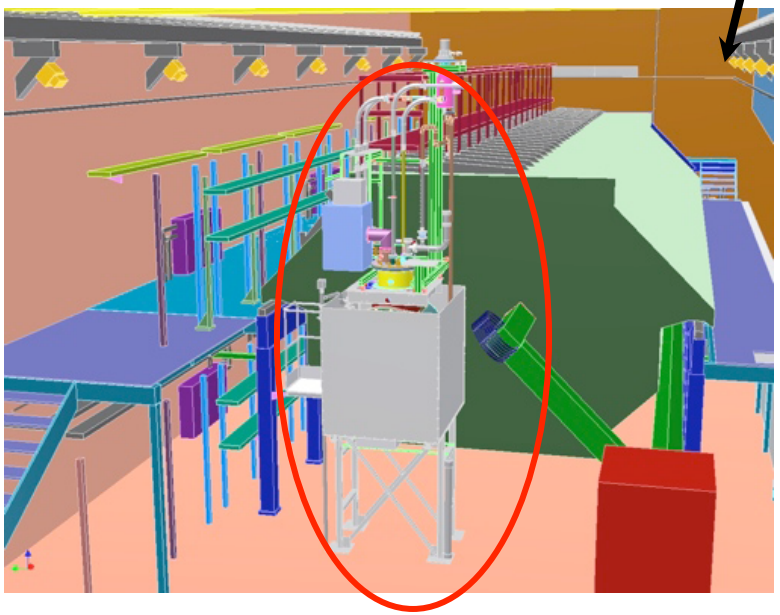
- ✓ ArgoNeuT is a 175 liter (active) Liquid Argon Time Projection Chamber (LArTPC)
- ✓ Jointly funded by DOE/NSF
- ✓ Designed and assembled in 2007-08, first commissioned (on surface) at FNAL in Summer 2008
- ✓ Moved underground in the *NuMI* beam at FNAL, in front of *MINOS Near Detector*, early 2009
- ✓ Phase I: Exposure to $\nu/\overline{\nu}$ beam (*LE beam option*): June'09 ⊕ Sept'09-Feb.'10

- ✓ ***Phase II - (second run):*** *in the BOOSTER low-energy nu-beam (SciBooNE enclosure) - 2011*



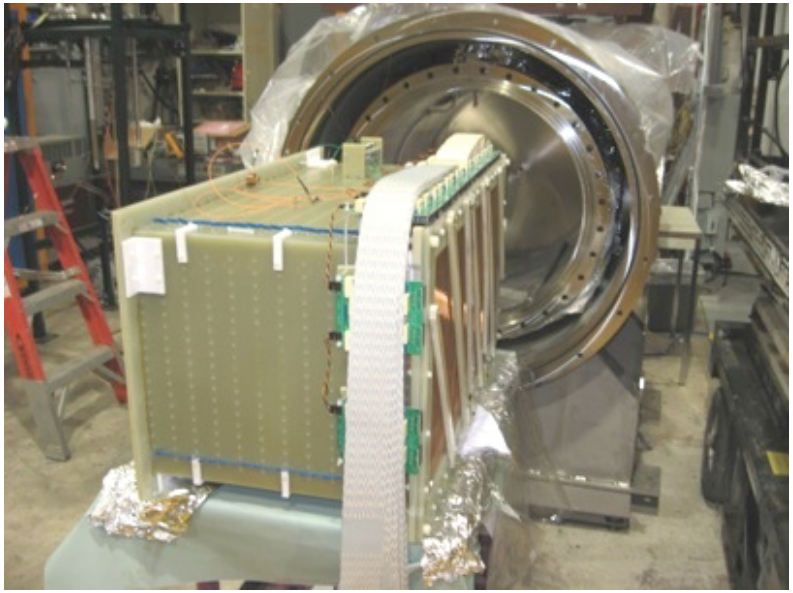
Fermilab, NuMI beam line





MINOS Hall: ArgoNeuT just upstream of the MINOS ND

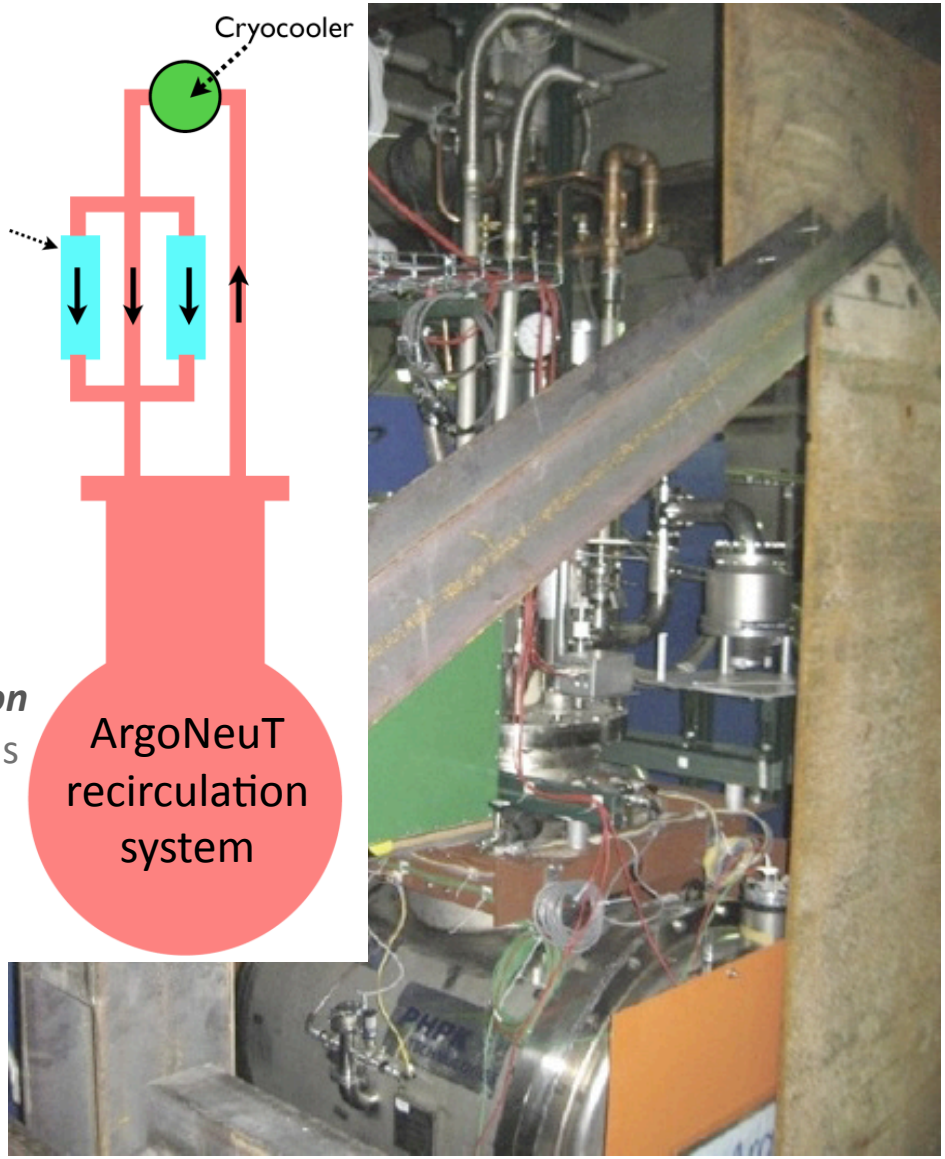
ArgoNeuT Design



The TPC, about to enter the inner cryostat

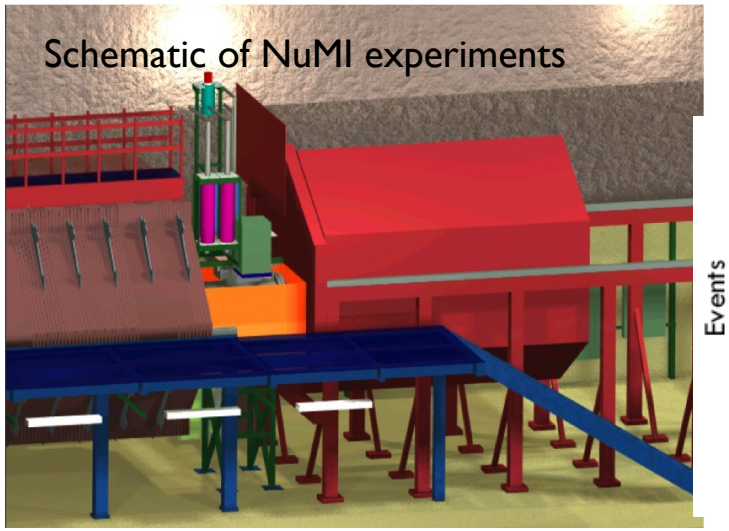
2 read-out planes: ***Induction and Collection***
each channel: 2048 samples in 400 microseconds

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330μs)
Electric field	500 V/cm



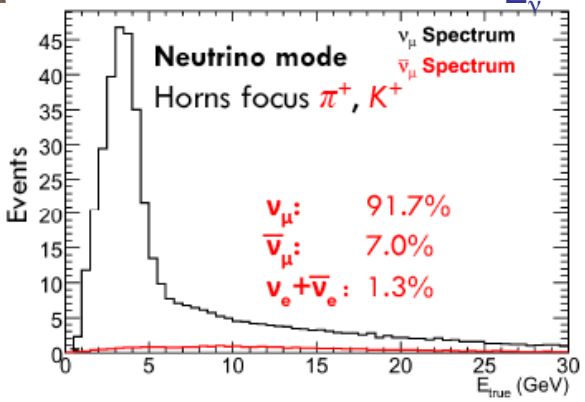
The fully-instrumented detector in the beamline

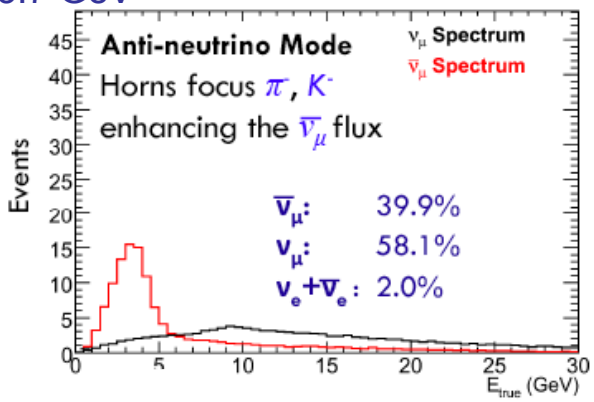
ArgoNeuT's physics run in the NuMI beam

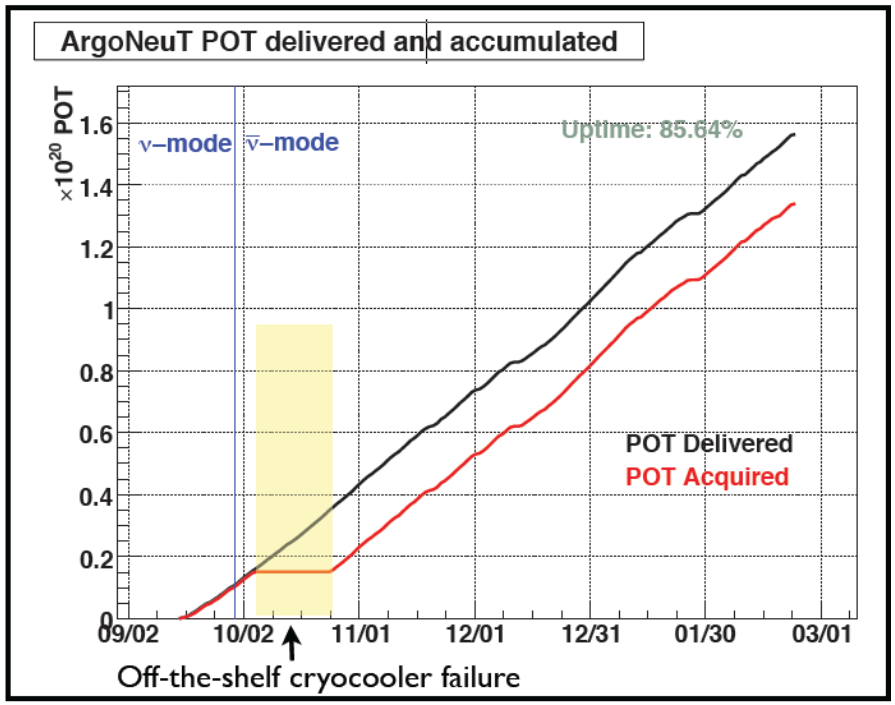


NuMI beam Fluxes - Low Energy (LE) mode

$\langle E_\nu \rangle$= 3.7 GeV







Reaction	#events in (~1.35E20 POT)
ν_μ CC	~6600
$\bar{\nu}_\mu$ CC	~4900
ν_μ CCQE	~600
ν_e CC	~130

✓Stable, shift-free operation for >5 months!

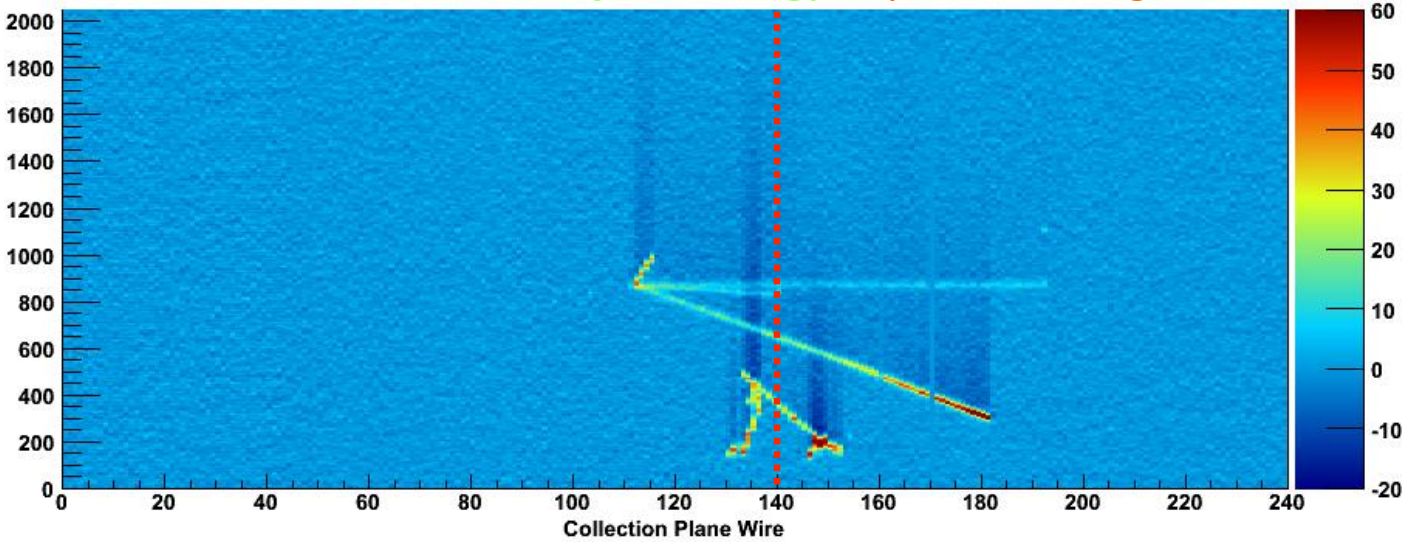
✓The first 1000s of (anti-)neutrino LArTPC events collected in a low-energy (~3 GeV) neutrino beam ever!

(Neutrino) Event Display

The detector provides two 2D-views of the event.

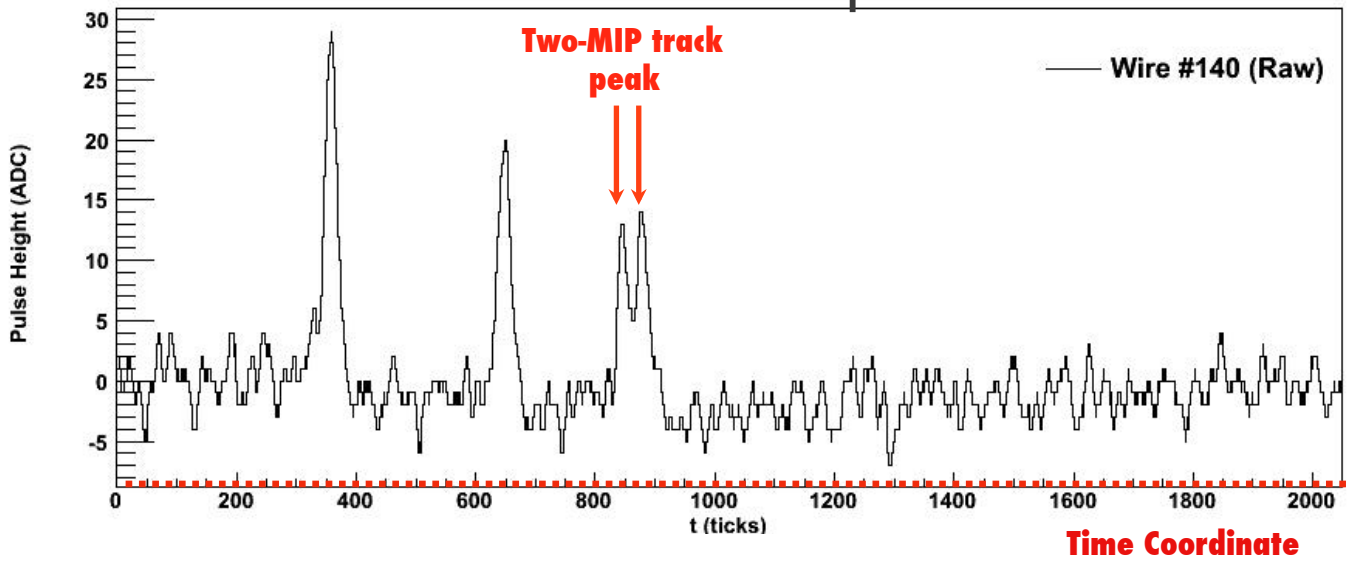
The color scale is indicative of the energy deposited along the track.

- m.i.p. yield: ~6000 e/mm
- Very fine pixel size (4mmx4mm x 0.3mm)
- Dark "shadow bands" are due to electronics returning to baseline...



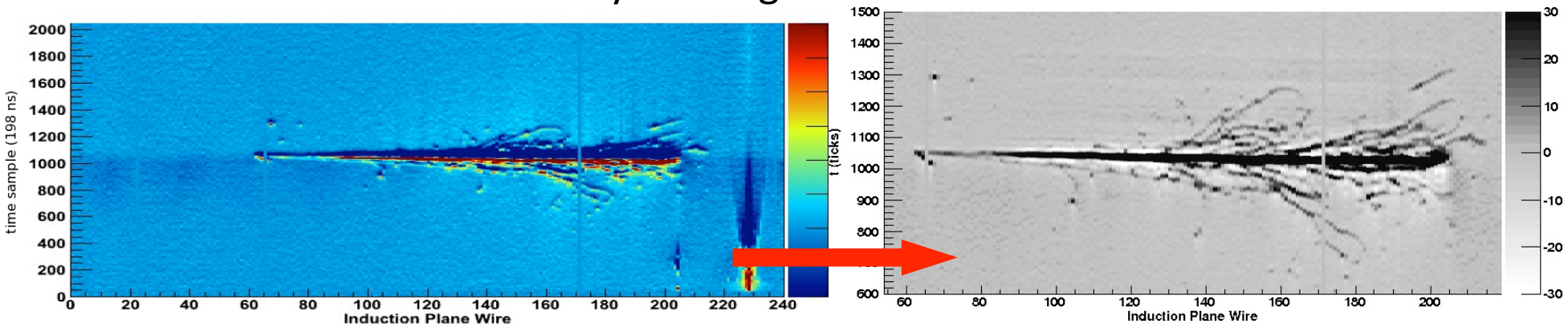
- Fourier decomposition (FFT) to remove electronics response (Filtering).

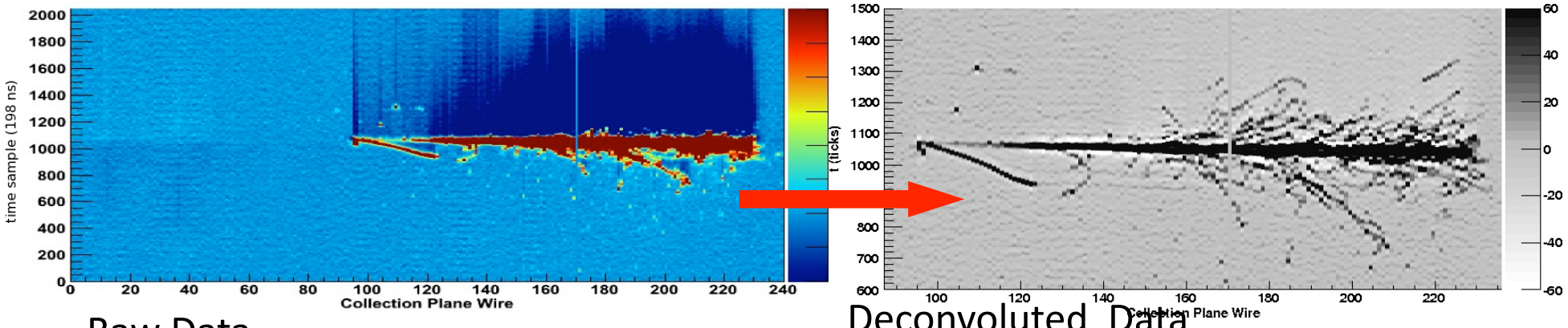
Wire pulse



Neutrino Event – ν_e

El.m. shower (not fully contained) +
short densely ionizing track at the vertex





Raw Data

Deconvoluted Data

✓This (beam-intrinsic) event demonstrates what a signal-like electron-neutrino event looks like to in LArTPC.

✓Current and future long baseline neutrino oscillation experiments (MINOS, T2K, NoVA, LBNE, ...) search for electron-neutrino appearance in order to measure θ_{13} and δ_{CP}.

ν event Reconstruction

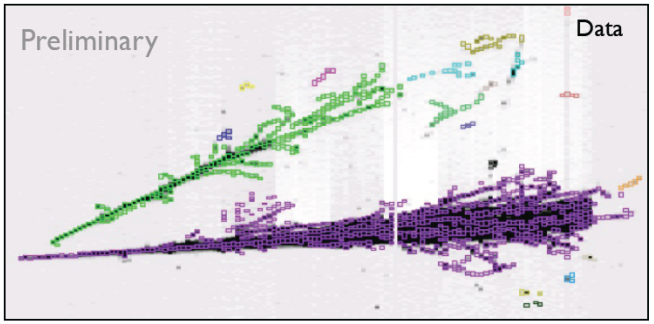
Offline reconstruction procedure:

1. Hit identification

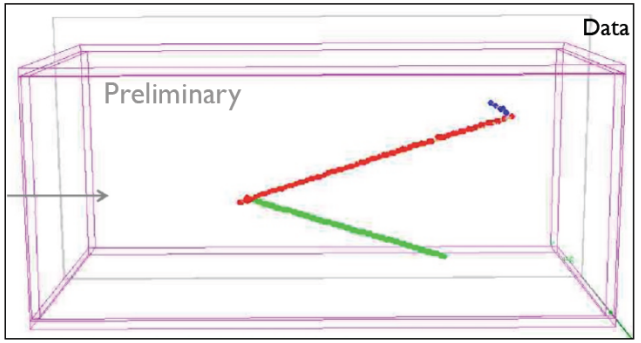
2. *Hit reconstruction*

3. *Cluster/Vertex reconstruction*

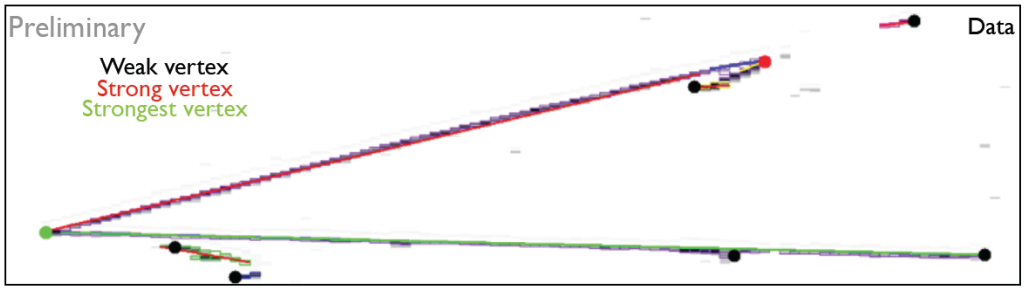
4. *3D track reconstruction*



Hit finding + density-based clustering.



3D reconstruction



Track finding/fitting + vertex/endpoint finding

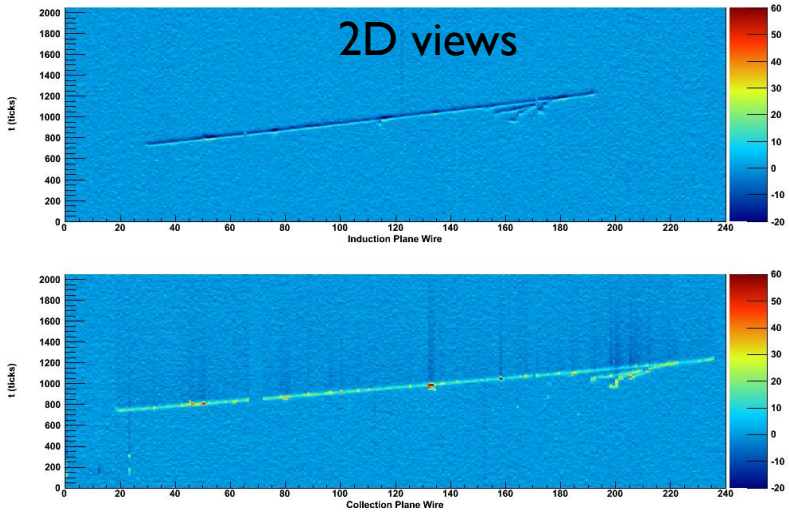
5. Matching ArgoNeuT tracks with downstream MINOS ND

for escaping muon momentum reconstruction and sign determination

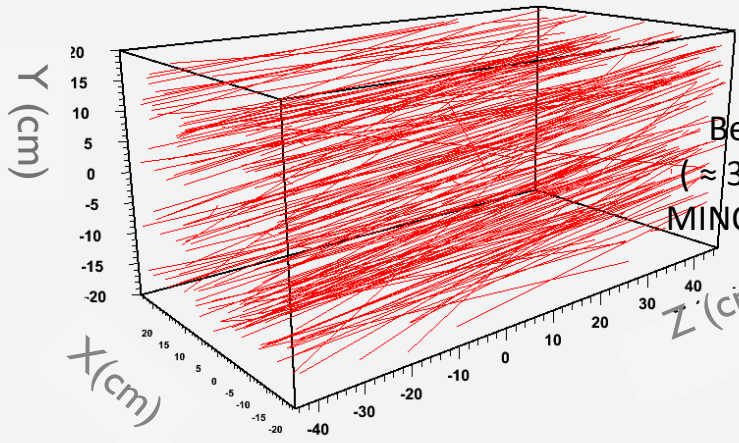
6. *Calorimetric reconstruction*

7. *Particle Identification (*dE/dx along the track*)*

μ from upstream ν beam interaction



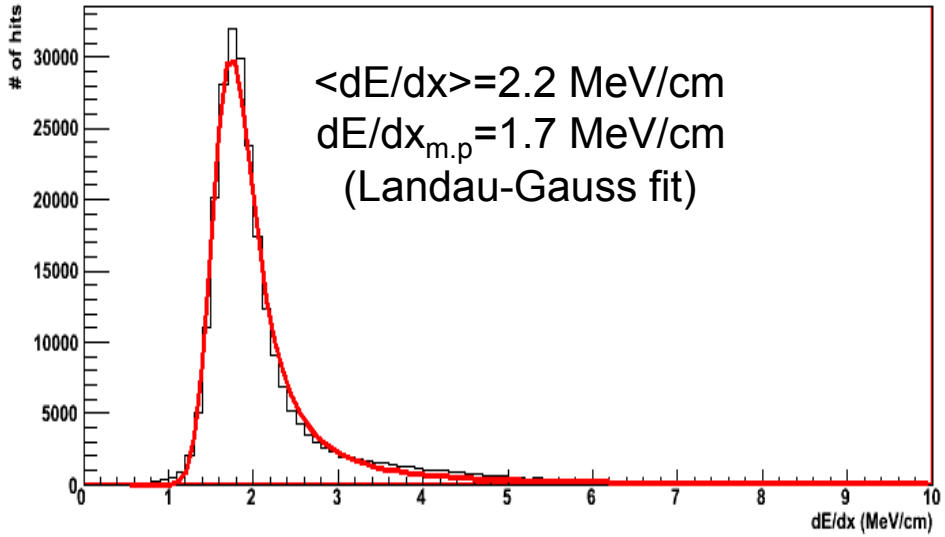
3D reconstruction



Beam direction
(~ 3° downward to
MINOS Far Detector)

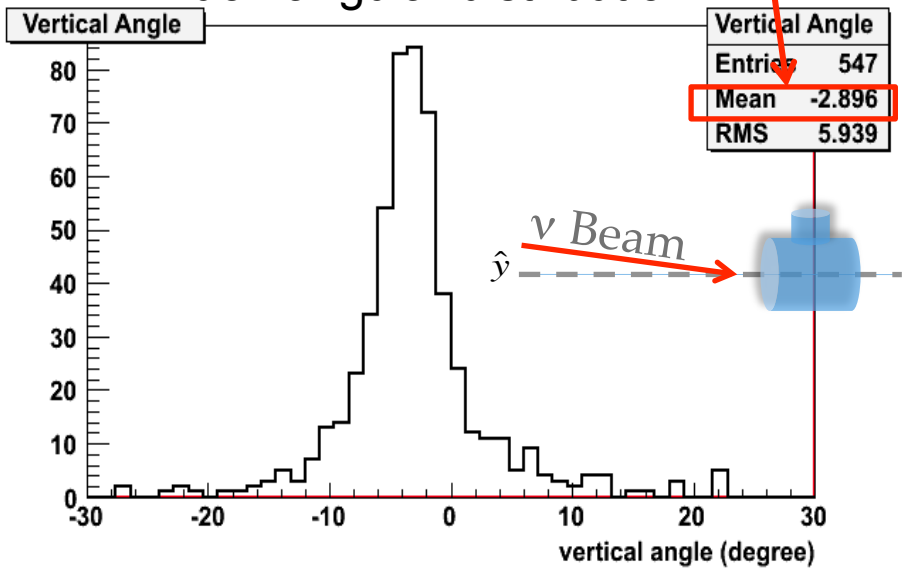
(**many**) crossing μ's superimposed in 3D view

Muon calorimetric reconstruction

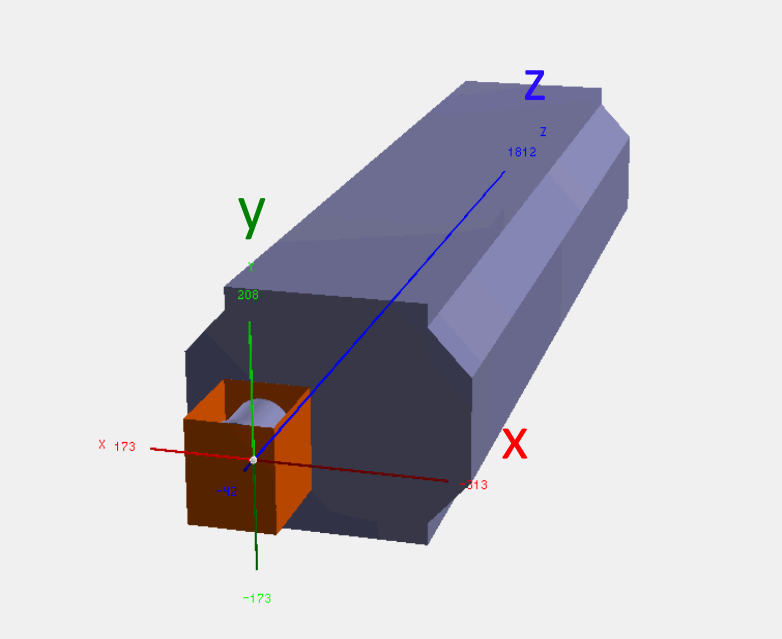


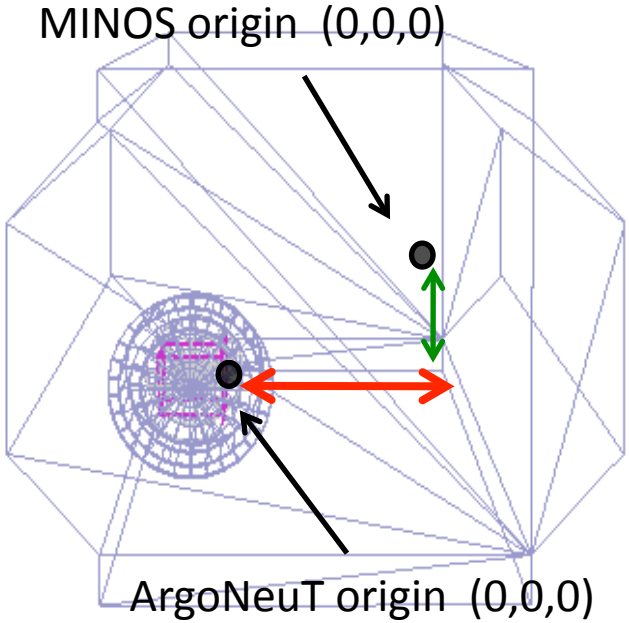
<dE/dx>=2.2 MeV/cm
$dE/dx_{m.p}$=1.7 MeV/cm
(Landau-Gauss fit)

Muon angular distribution



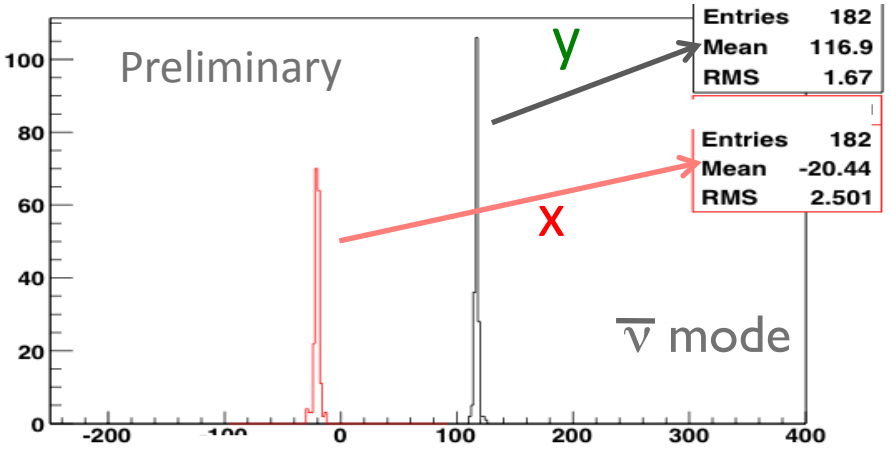
μ from upstream $\overline{\nu}$ beam interaction: Matching with MINOS ND (I)



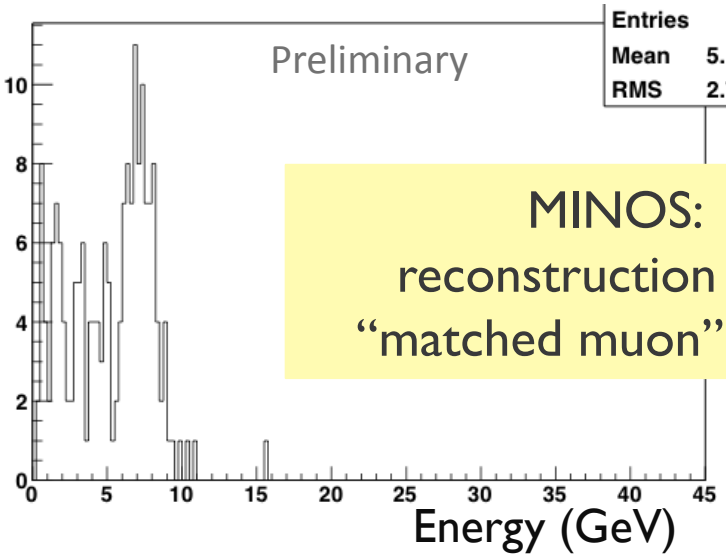


Tracks whose direction extrapolated from ArgoNeuT matches a MINOS track

Difference between horizontal coordinates and vertical coordinates of the "matched tracks"

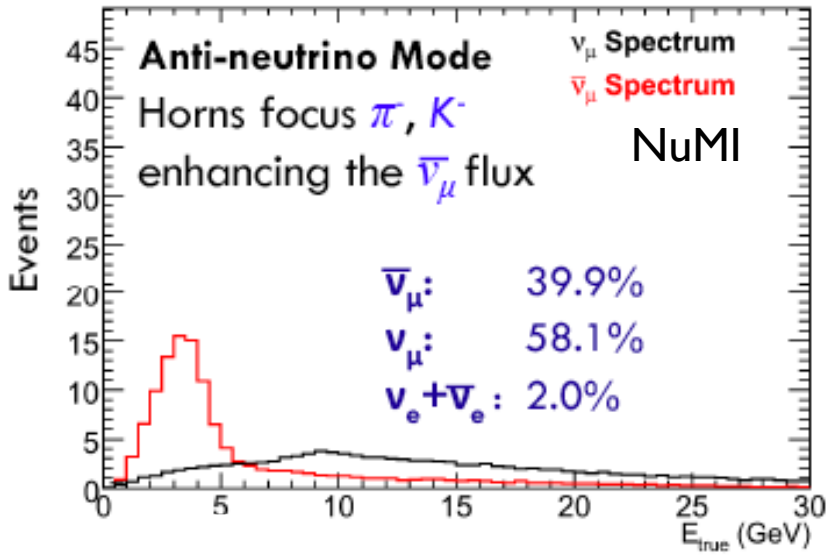


μ from upstream $\bar{\nu}$ beam interaction: Matching with MINOS ND (II)

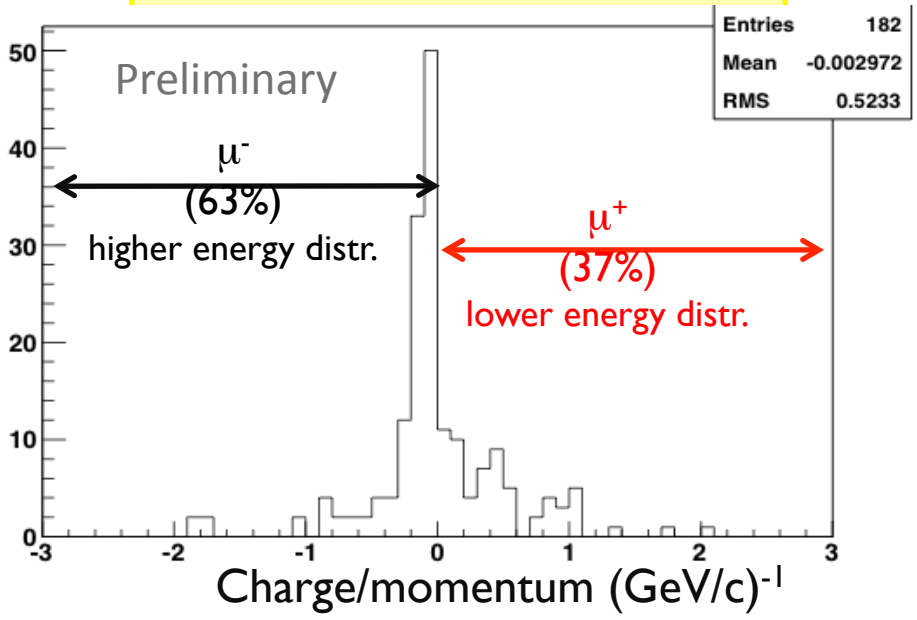


Muon momentum reconstruction from MINOS ND:
-by curvature in magn. field - 12% resolution for a 10 GeV muon
- by range for stopping muons ~6% resolution)

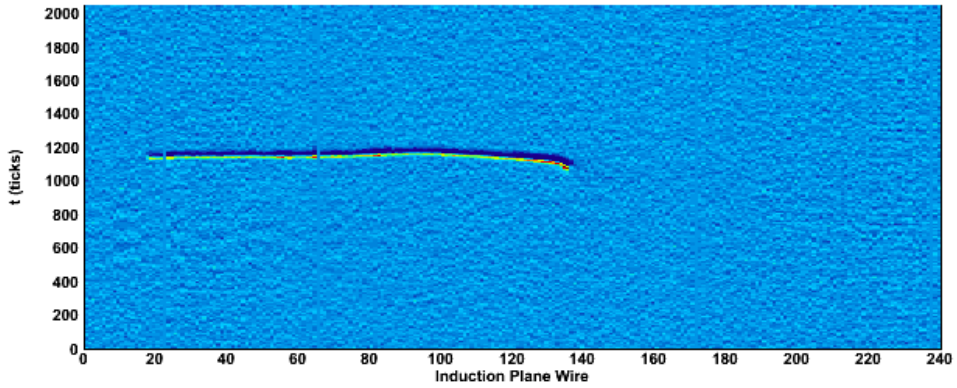
MINOS:
reconstruction of the
"matched muon" energy

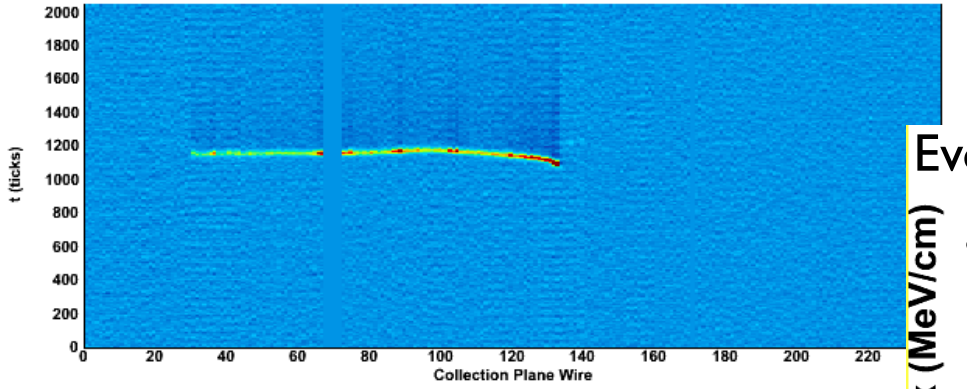


MINOS:
measurement of the
"matched muon" sign



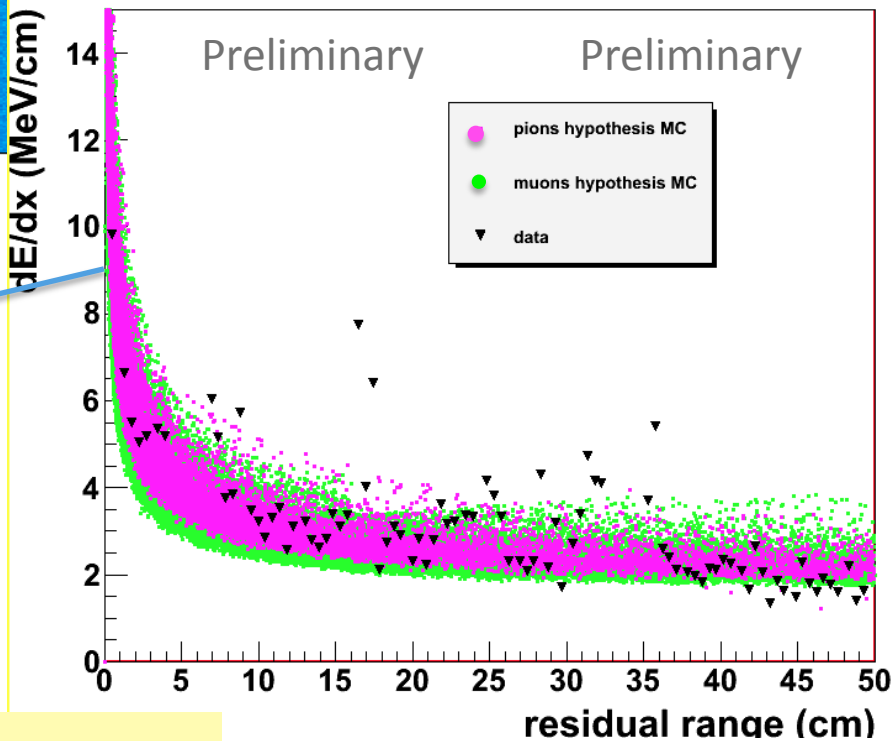
Particle ID





Penetrating particle
(from upstream interaction)
stopping in LAr volume

Evolution of the ionization along the track



Minimum ionizing ptcl:

muon or pion

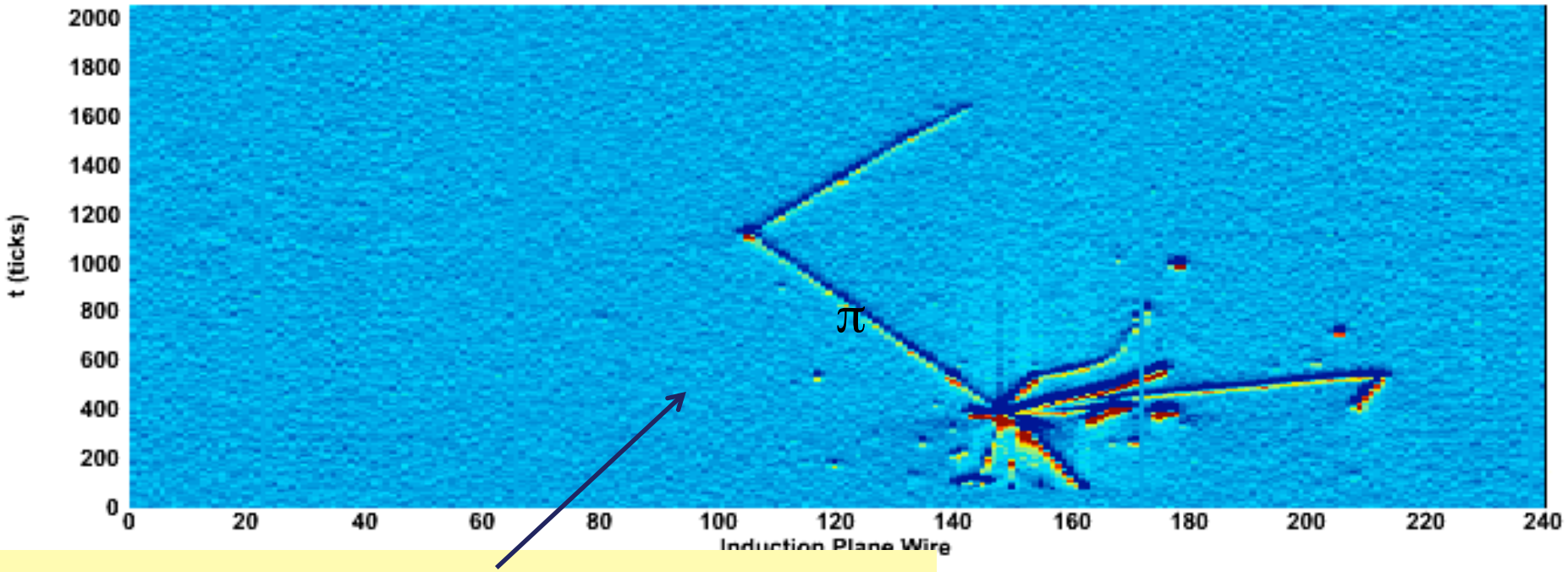
Track lenght= 52 cm

Kinetic Energy=160 MeV

(in agreement with expectations GEANT)

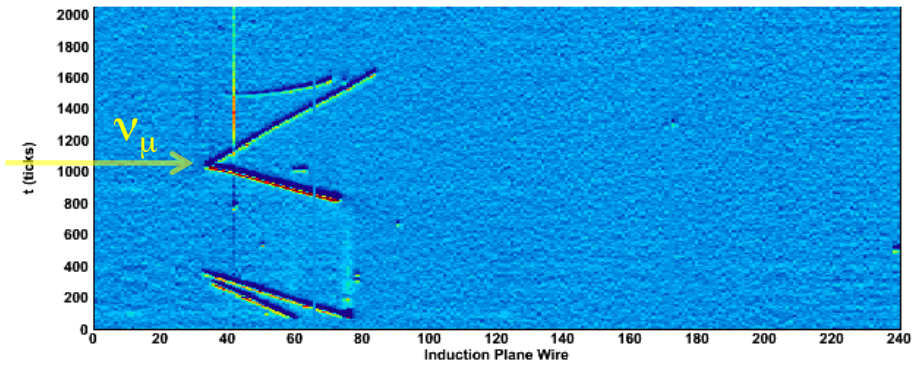
Muon-Pion separation possible only in same cases

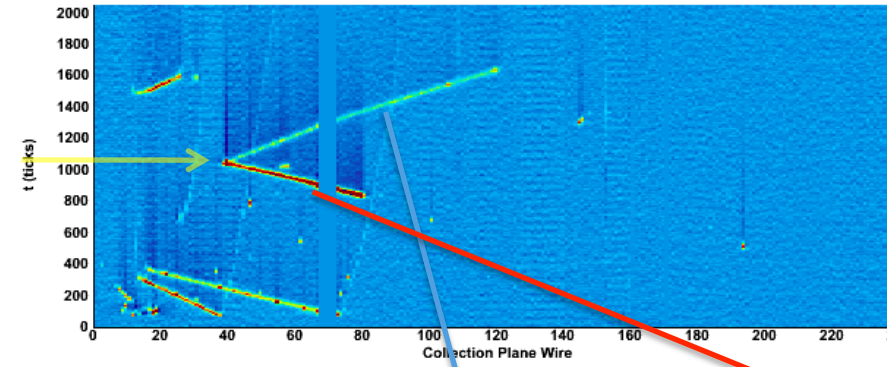
Particle ID



Muon-Pion separation possible only in same cases

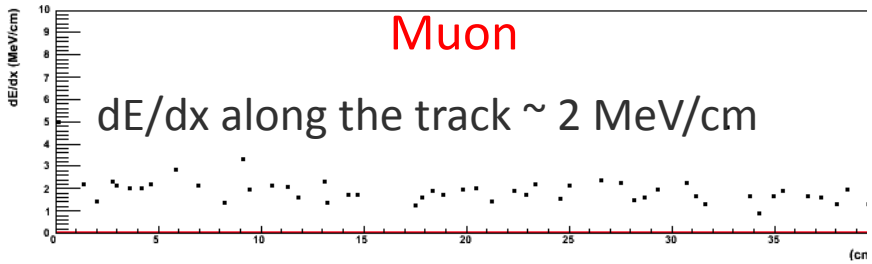
ν_μ CC QE event reconstruction





m.i.p. particle

Muon



dE/dx along the track ~ 2 MeV/cm

ν Interaction in LAr volume

μ+p (ν_μ CC QE event)

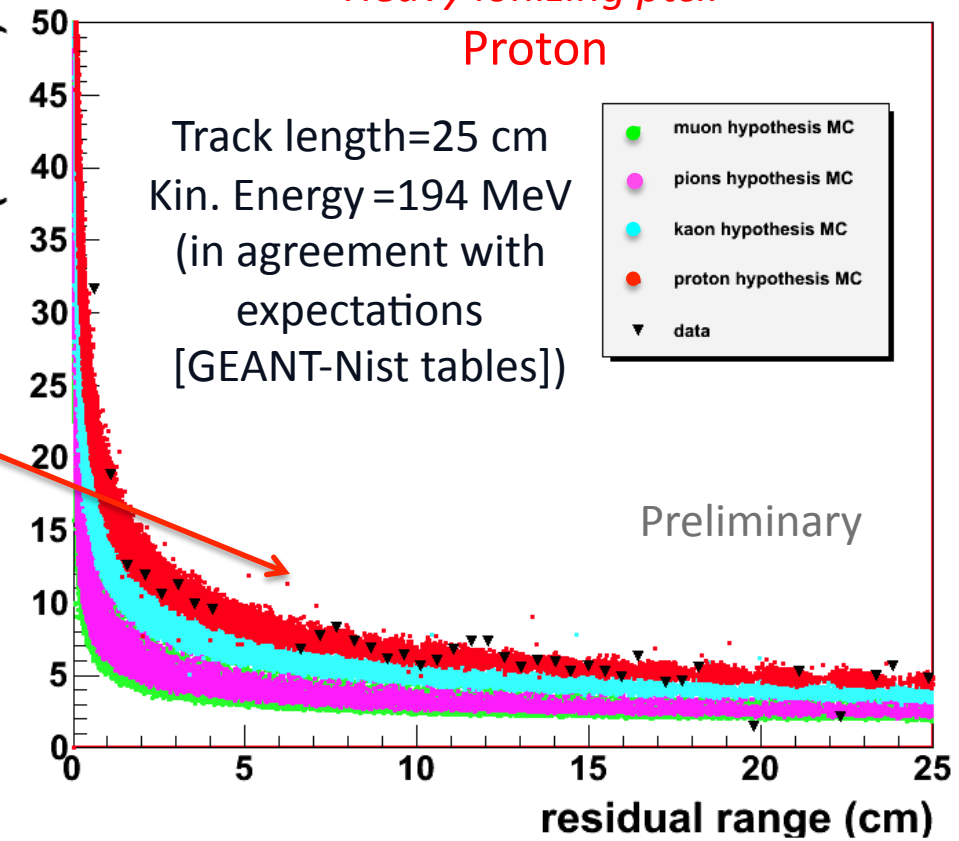
+

uncorrelated tracks from upstream neutrino interaction

Heavy ionizing ptcl.

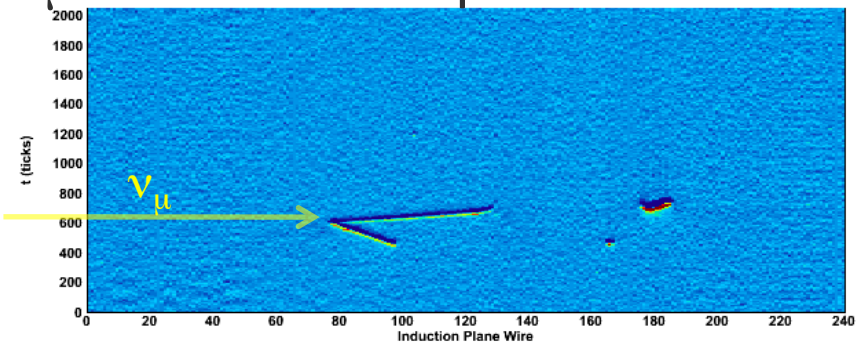
Proton

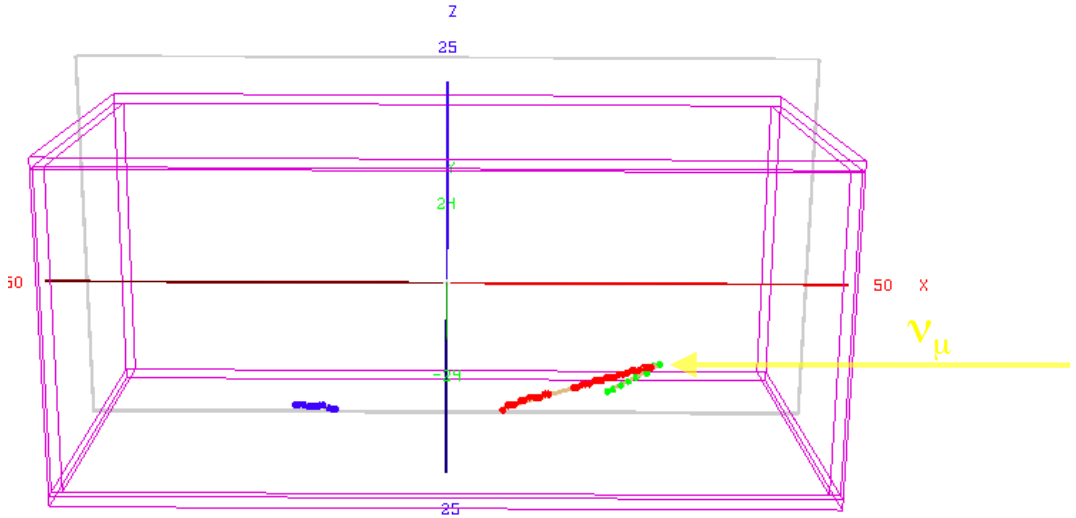
Track length=25 cm
Kin. Energy =194 MeV
(in agreement with expectations [GEANT-Nist tables])

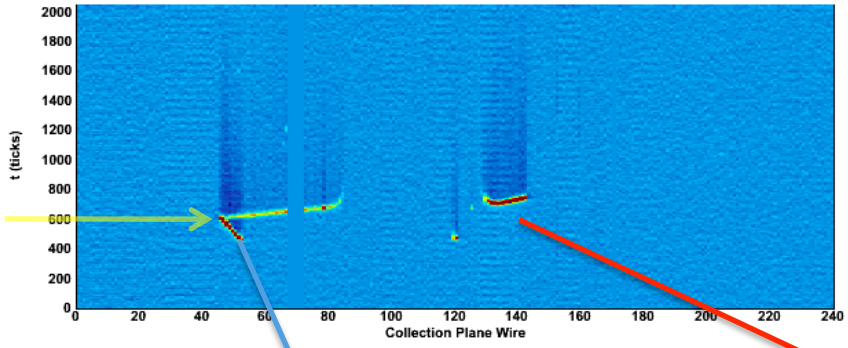


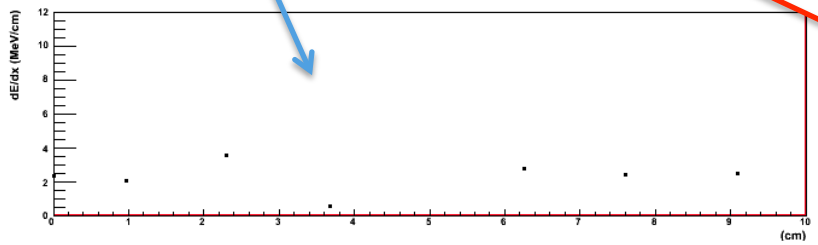
ν interaction in LAr

μ + π event + proton track







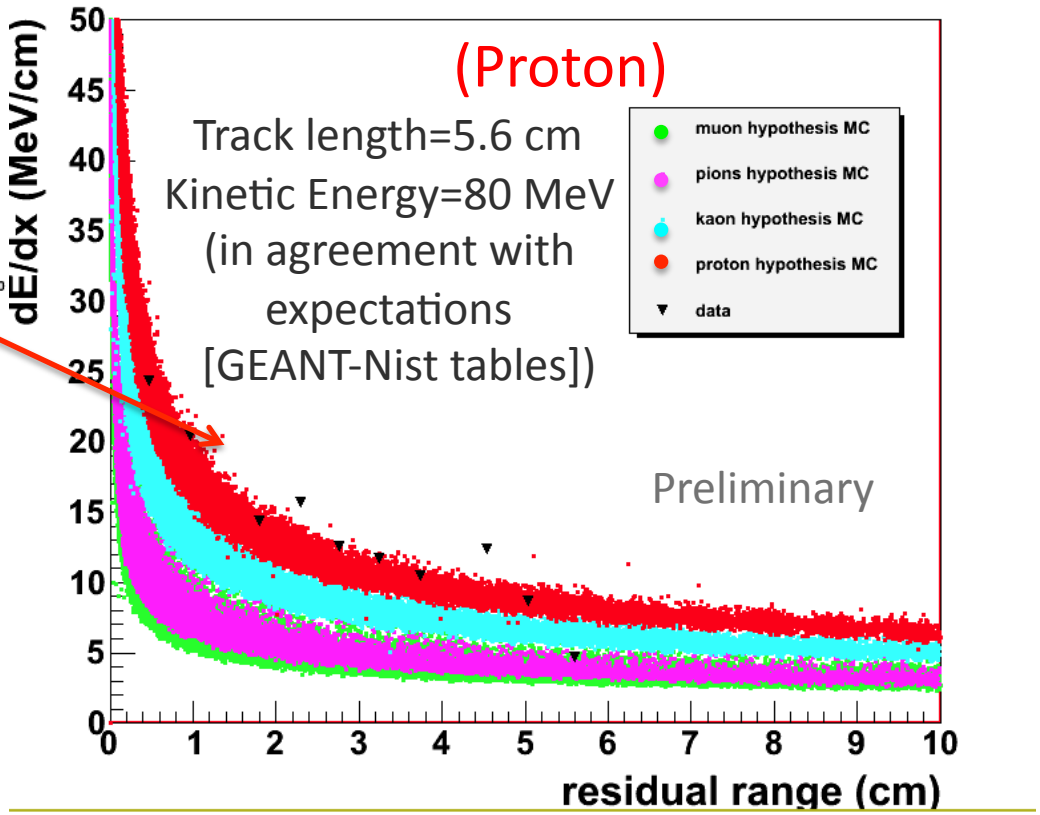


2 m.i.p. particles (μ + π) at vtx

[*faking a QEL signature (μ + p)*]

+

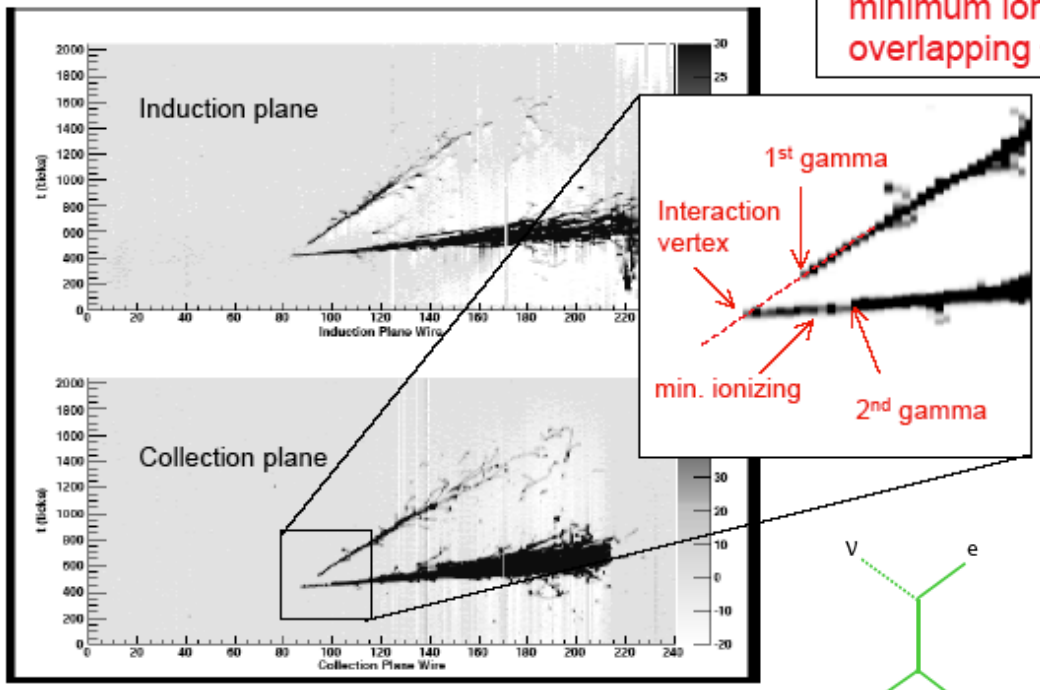
proton track (far from vtx.)

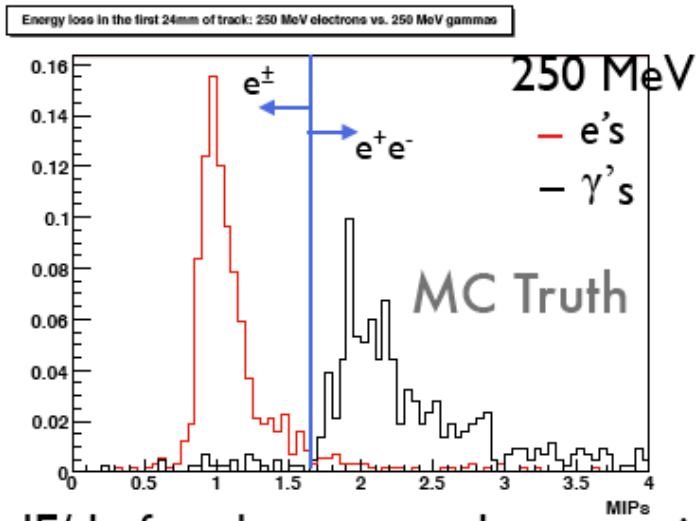


PID: e/γ separation study and optimization

- Photon conversion background to ν_e interactions
  - Separation from primary vertex or by double ionization
  - γ-conversion over a minimum ionizing track requires excellent pair resolution

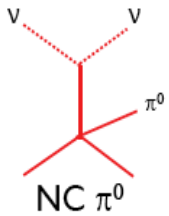
Careful inspection yields a minimum ionizing track with overlapping γ conversion





dE/dx for electrons and gammas in first 2.4 cm of track

$\pi^0 \rightarrow \gamma\,\gamma \rightarrow (e^+e^-)\,(e^+e^-)$



For *e+e-* efficiency > 80%, *e* contamination < 5%

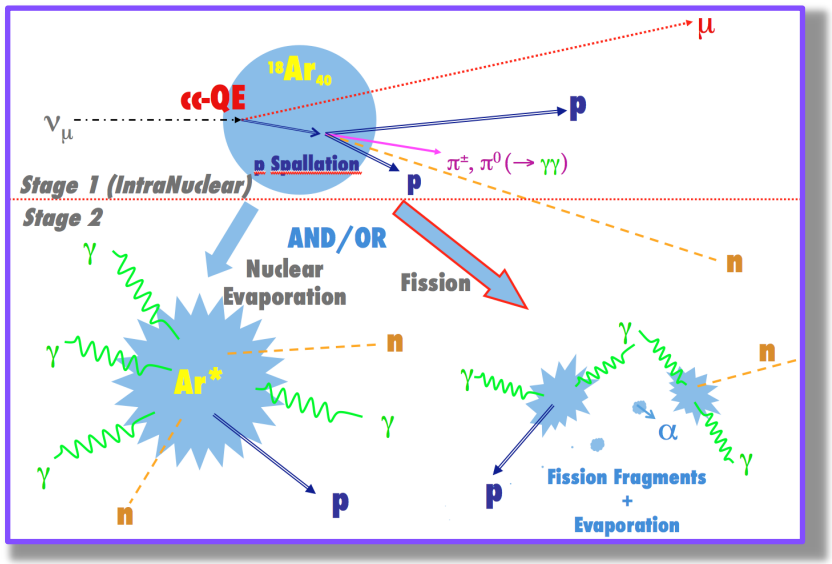
Understanding vertex activity

"Final State (re)-Interactions"- *the main source of uncertainty*:

even the "easiest" topology (CC-QE) is not so simple

$\nu_\mu + n \rightarrow \mu^- + p$ (reaction on free nucleon)

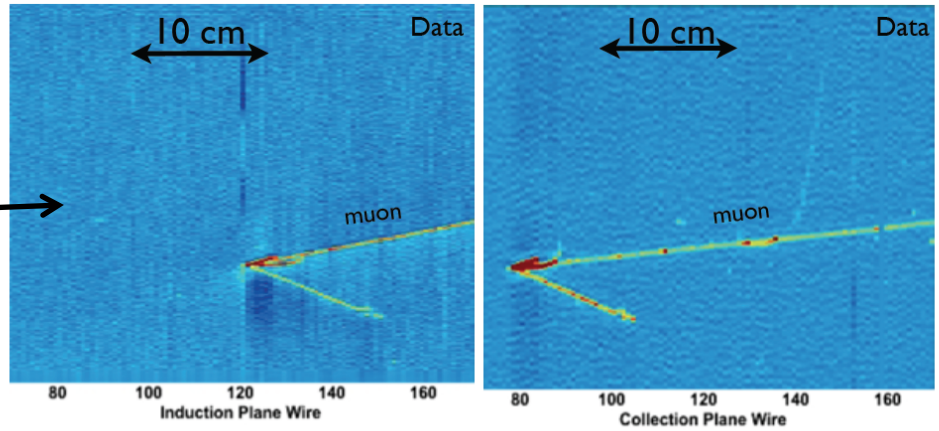
$\nu_\mu + A(n) \rightarrow \mu^- + p + (A-1)^*$ (nucleon bound in the nuclear target)



FSI

- ***proton Spallation*** (intranuclear interactions with **p** and **n** emission ...but also $\pi^\pm$, π^0)
- ***Nuclear evaporation*** (lower kin.en. **p** and **n**)
- (and/or) ***Fission*** (nuclear fragments, α's,..)
- ***Nuclear de-excitation*** with **γ** emission

These products are usually neglected because not detectable, unless... .... a high quality imaging detector is in use !!



A zoomed-in view of a CCQE-like neutrino event with evidence of vertex activity

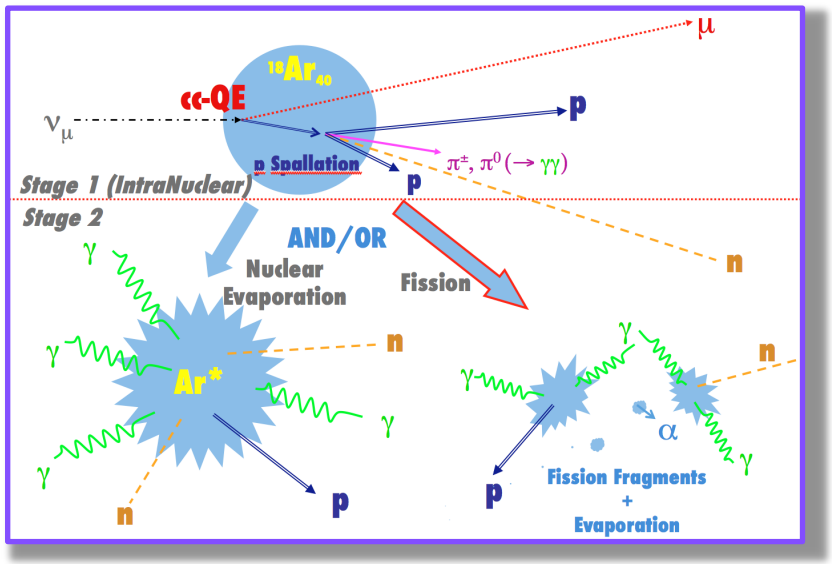
Understanding vertex activity

"Final State (re)-Interactions"- *the main source of uncertainty*:

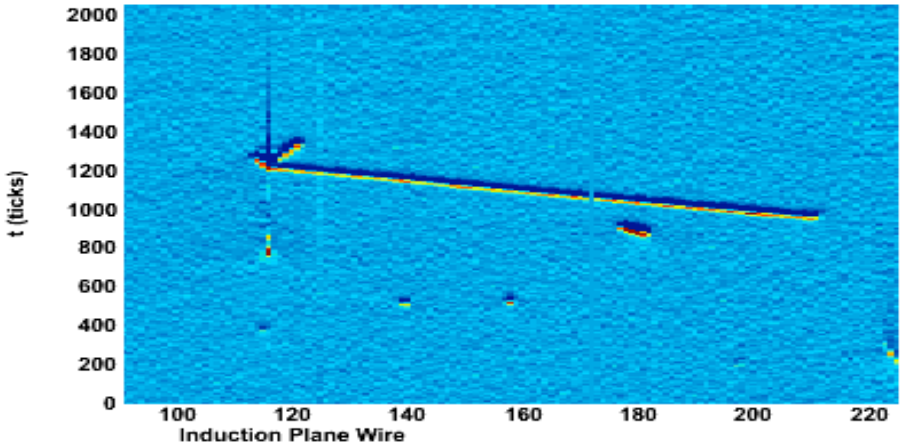
even the "easiest" topology (CC-QE) is not so simple

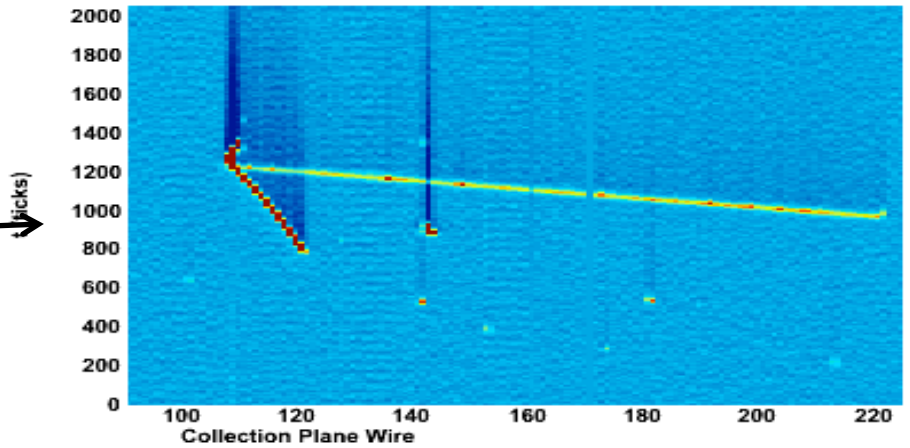
$\nu_\mu + n \rightarrow \mu^- + p$ (reaction on free nucleon)

$\nu_\mu + A(n) \rightarrow \mu^- + p + (A-1)^*$ (nucleon bound in the nuclear target)



FSI





These products are usually neglected because not detectable, unless… …. a high quality imaging detector is in use !!

A zoomed-in view of a CCQE-like neutrino event with evidence of vertex activity

ArgoNeuT Collaboration

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Conclusions

Next-generation neutrino physics experiments require precision
Particle IDentification and
fine grained 3D imaging on very large scale.

Liquid Argon TPC combines an ideal detection medium with a modern imaging and calorimetric readout technique, scalable to very large volume/mass.

ArgoNeuT is a fully operational LArTPC: during the (first) ν-run, large samples of neutrino/antineutrino events have been collected for the 1st time ever in a low-Energy beam.

The extension to a second run period is being proposed at FNAL

Extensive Real data/experience is invaluable in improving LArTPC technique.
Analysis software is being developed as general purpose tool for future LArTPCs.
Highly sophisticated/detailed MonteCarlo codes are needed,
and are currently under test/optimization